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INFORMATION PERCEIVED IN SIMULATED SCENES DISPLAYED WITH REDUCED FIELD OF VIEW: A FURTHER EXPERIMENT

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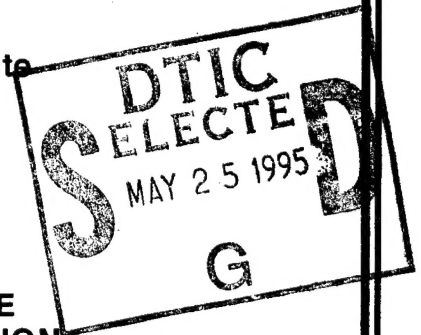
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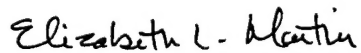19950524 013

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A previous experiment revealed that subjects perceive variation in three different properties of flight simulator visual scenes during low-altitude, high-speed flight. When field of view was reduced, however, the same scene elements were no longer perceived as being uniquely different from one another but combined to mediate a single factor related to scene complexity. The present experiment sought to determine whether this difference could be attributed to lack of optic flow structure off-axis from the heading direction. The same stimuli were shown on a single display window that was oriented to the side of the aircraft rather than in the direction of heading. Results were more similar to those obtained with a full three-window display configuration, thus suggesting that important information for distinguishing among various scene elements is obtained exclusively off-axis from the heading direction.

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PREFACE

INFORMATION PERCEIVED IN SIMULATED SCENES DISPLAYED WITH REDUCED FIELD OF VIEW: A FURTHER EXPERIMENT

INTRODUCTION

In a previous investigation, Kleiss (in press) sought to identify the elements of flight simulator visual scenes that affected perception during low-altitude, high-speed flight. An analysis of simulated scenes using multidimensional scaling (MDS) revealed that scene perception was affected by three distinctly different scene elements: texture on terrain, objects, and terrain shape. The finding that objects and terrain shape define separate scene dimensions replicates previous MDS results obtained using images of real-world scenes (Kleiss, 1992a). The finding that texture defines a third dimension is consistent with evidence that texture and objects each provide different information for perceiving altitude in flight simulators (DeMaio, Rinalducci, Brooks, & Brunderman, 1983; Kleiss & Hubbard, 1993). Kleiss' (in press) results, therefore, reveal a potentially rich array of information available in flight simulator visual scenes including that which has previously been found to be important in real-world scenes.

The display used in the experiment described above (Kleiss, in press, Exp. 1) consisted of three pentagonal screens arrayed horizontally around the observer with the middle screen centered on the heading direction. The horizontal field of view was approximately 210 deg and the vertical field of view was approximately 100 deg. When the field of view was reduced in Experiment 2 by displaying scenes only on the center window (80 deg H by 70 deg V field of view), results changed notably. Instead of three dimensions, there was only one clearly interpretable dimension which related to global scene complexity and reflected a composite of texture, objects, and hills. These results draw attention to a perceptual limitation related to field of view. The nature of the limitation is interesting because it did not derive from a failure to perceive various elements in scenes, but from a failure to perceive them as being uniquely different from one another. Hence, there is information potentially available in scenes that is of a higher order than the mere presence of various scene elements. This information is dependent upon field of view.

Wolpert (1990) noted that two different types of information vary as a function of field of view. With a large field of view, there is greater peripheral stimulation of the retina. A large field of view oriented in the direction of heading also affords the opportunity to direct one's gaze to regions of the environment off-axis from the heading direction. The basis for this second type of information lies in the fact that optic flow structure off-axis from the heading direction differs notably from that in the direction of heading (Koenderink & van Doorn, 1987, cited by Wolpert, 1990). Specifically, scene elements in the direction of heading flow outward from the vanishing point in an expanding pattern. As one samples regions of the environment at greater eccentricities from the heading direction, optic flow becomes increasingly lamelar (parallel). The effect of

reduced field of view reported by Kleiss (in press) could reflect either reduced peripheral stimulation of the retina or reduced parallel optic flow information. Evidence suggests that parallel optic flow may be the more important factor for perceiving self-motion events such as change in speed and altitude (Wolpert, 1990) as well as heading direction (Warren & Kurtz, 1992), although Crowell and Banks (1993) provide counterevidence in the case of heading perception.

If far peripheral stimulation of the retina is important for perceiving multidimensional scene structure, then a display equal to or smaller in size than the single forward oriented window used by Kleiss (in press, Exp. 2) would not be adequate. However, if optic flow structure off-axis from the heading direction is important, then such information might possibly be provided with a small display that could be moved to reveal different regions of the environment (e.g., a helmet-mounted display or a multi-window display with switchable image channels). The influence of optic flow structure off-axis from the heading direction could be explored with the display of Kleiss (in press) by projecting imagery on a single side window. Assuming that subjects directed their gaze toward the side window, peripheral stimulation of the retina would be equal to that with the single forward window. Optic flow structure, however, would be considerably different from that available with the single forward window. If optic flow structure off-axis from the heading direction is the important factor mediating multidimensional scene structure with the full three-window display configuration, evidence of multidimensional scene structure should also be obtained with the single side window. If far peripheral stimulation of the retina is important, there should be no evidence of interpretable multidimensional scene structure with the single side window.

METHOD

Subjects

Four females (mean age 44 yr) and six males (mean age 27 yr) participated in the experiment as paid volunteers. All had normal-or-corrected to normal visual acuity. One male was an Air Force pilot qualified for fighter aircraft who was not currently on flying status (1700 hr total flying time). The MDS algorithm used to analyze data (ALSCAL for PCs, Young, Takane & Lewyckyj, 1978) provides individual differences information allowing comparisons among subjects. However, previous research using a similar method (Kleiss, in press, Exp. 1; Kleiss, 1992b) failed to reveal such differences.

Apparatus

Scenes were generated by the Advanced Visual Technology System (AVTS) (see Eibeck & Petrie, 1988 for specifications). Among its capabilities is cell texturing, a technique by which a

complex digitized pattern can be rendered on a surface by modulating the lightness and darkness of the surface. The display consisted of three pentagonal screens arrayed horizontally within a dodecahedral frame. In the center of the dodecahedron was a simulated jet fighter cockpit with nonfunctional instrumentation. The middle display screen was centered on the front of the cockpit. Display screens measured 1.75 m by 1.32 m (approximately an 80 deg by 70 deg viewing angle from a distance of 1 m). Imagery was displayed on the left screen only which spanned the region from about 20 deg left of heading to about 100 deg left of heading. Vertically, the display window spanned the region from about 20 deg above the horizon to about 50 deg below the horizon. The center and right screens contained a neutral gray field equal in luminance to the sky in stimulus scenes (31.656 Cd/m^2). The projectors were Barco CRT projectors. Maximum addressable resolution was 1,000 lines by 1,000 elements/line. The display was interlaced at 60 Hz update rate. Subjects were seated in a jet-fighter cockpit oriented in the direction of heading with no functioning instruments or controls.

Stimuli, Design, and Materials

Stimuli were 5-s segments of straight-and-level flight through a variety of computer-generated scenes. Speed was constant at 450 kn and altitude was constant at 45.73 m (150 ft) above the highest point of the terrain. When hills were present, therefore, altitude was 45.73 m above the tops of hills. Speed and altitude are typical of jet-fighter aircraft during combat missions.

There were four levels of terrain shape: (a) flat, (b) rolling, (c) sparse hills, or (d) dense hills. Rolling terrain, sparse hills, and dense hills each contained hills that extended vertically about 19.82 to 22.87 m. The tops of hills were diamond-shaped plateaus measuring 22.87 m in the direction of heading and 45.73 m perpendicular to the direction of heading. The three types of terrain differed with respect to the slope and/or spacing of hills. Rolling terrain comprised hills with sides sloping gradually upward about 4 deg from horizontal. The average center-to-center spacing of rolling hills was about 732 m. Adjacent hills were joined such that no flat terrain was visible between them. The sides of both sparse hills and dense hills sloped upward about 13 deg from horizontal. The average center-to-center spacing of dense hills was about 244 m. The sides of adjacent hills were joined such that no flat terrain was visible between them. Terrain with sparse hills was made by removing about 60 % of the hills from terrain with dense hills such that hills were separated by intervening flat terrain.

There were four levels of scene elements on the terrain: (a) no texture or trees, (b) a textured pattern on the terrain, (c) texture plus evenly spaced trees, and (d) texture plus trees clustered into groups. Untextured flat terrain was a uniform shade of green exhibiting a luminance of 1.555 Cd/m^2 measured with a Photo Research Model PR703A spectral scanner. Polygons in

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scenes containing untextured hills differed somewhat in luminance to enhance contrast. The sides of hills were 1.555 Cd/m^2 whereas the tops of hills were 2.354 Cd/m^2 and intervening flat terrain, when present, was 1.939 Cd/m^2. A shading algorithm available with AVTS also produced small variation in the brightness of surfaces depending on their relationship to the sun. Texture consisted of an irregular pattern of blotches exhibiting approximately the same three luminances as described above. Mean luminance of texture sampled across a range of texture luminance values was 2.001 Cd/m^2. Trees were made by applying a digitized image of a 35-ft pine tree to object surfaces. Mean luminance of trees sampled across a range of texture luminance values was 0.637 Cd/m^2.

The four types of terrain shape and the four types of scene elements on the terrain yield a total of 16 unique combinations. From these 16 scenes, Kleiss (in press, Experiment 2) selected a subset of 12 which will be used in this experiment. The twelve scenes are listed below:

1. flat terrain with no texture or trees
2. flat terrain with texture
3. flat terrain with texture plus evenly spaced trees
4. rolling terrain with no texture or trees
5. rolling terrain with texture
6. rolling terrain with texture plus grouped trees
7. sparse hills with no texture or trees
8. sparse hills with texture plus evenly spaced trees
9. sparse hills with texture plus grouped trees
10. dense hills with texture
11. dense hills with texture plus evenly spaced trees
12. dense hills with texture plus grouped trees

Twelve stimuli yield a total of 66 unique pairwise combinations. Stimulus pairs were arranged in two random sequences with the order of stimuli in each pair reversed between sequences. Figure 1 shows a scene with dense hills and texture plus grouped objects.

Following Schiffman, Reynolds, and Young (1981), similarity judgments were recorded on 120-mm, ungraduated lines anchored at the left with "Same" and at the right with "Different." Rating scales were arranged in a booklet containing four scales per page, each numbered in sequence.
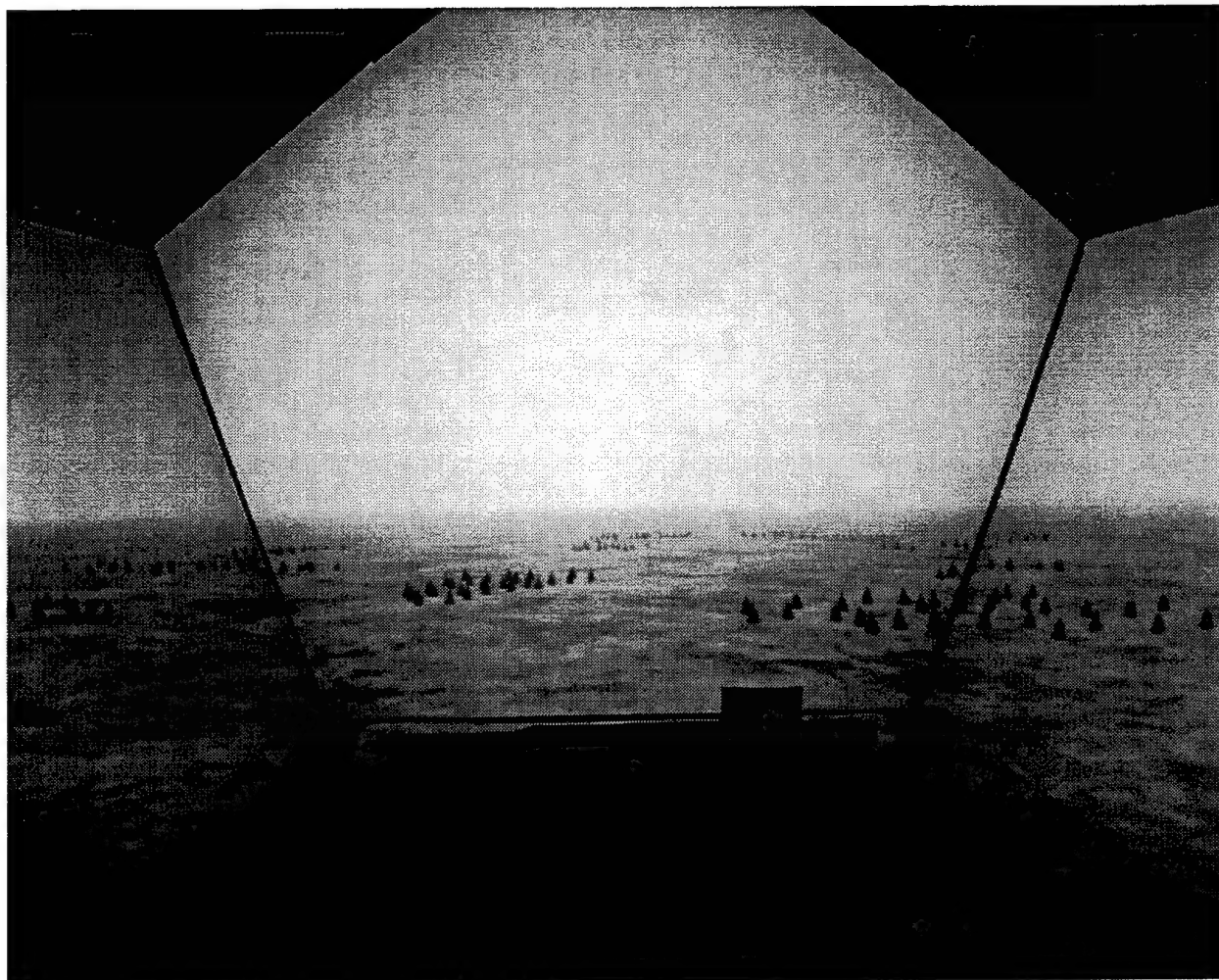
Figure 1
Scene with Flat Terrain and Grouped Trees

Procedure

Subjects were informed that the purpose of the experiment was to investigate flight simulator visual scene elements useful for perceiving one's motion during low-altitude, high-speed flight. They were told that they would be viewing short segments of flight through a variety of simulated scenes and that they would be judging the degree of similarity between scenes with respect to scene elements useful for perceiving motion. If the second scene looked the same as the first, a mark was to be placed at the extreme left end of the rating scale. If the second scene looked different than the first, a mark was to be placed somewhere along the scale indicating how different. Subjects were encouraged to base their ratings upon a general impression of similarity and not to analyze specific differences between scenes. Subjects were informed that speed and altitude would be constant across scenes. Scenes were to be presented sequentially in pairs. Scenes were displayed on the left-side display window and subjects were instructed to orient their eyes toward that window. To familiarize subjects with the range of scene elements depicted in scenes, scenes were first shown individually before presentation of stimulus pairs.

Each trial began with a uniform gray display field which remained visible until the subject pressed a button to display the pair of scenes. Scenes within each pair were separated by a uniform blue display field which remained visible for 2 to 4 s. The gray display field reappeared after the second scene and remained visible until the button was pushed to initiate the next trial.

RESULTS

Data were distances in millimeters measured from the left end of each scale to the point at which the subject marked the scale. The maximum range of values was 0 to 120 with larger values indicating greater dissimilarity. Rating data were submitted to multidimensional scaling using ALSCAL for PCs (Young, Takane, & Lewyckyj, 1978). A weighted (individual differences) approach was used which has several advantages over other approaches according to Schiffman, Reynolds, and Young (1981). First, it generally yields the most robust and reliable results. Second, spatial configurations are fixed in relation to dimensional axes and are, therefore, directly interpretable without rotation. Third, individual differences information is provided which reveals the relative importance of each dimension for individual subjects. Ratings were assumed to be ordinal and continuous.

Three measures describe the degree of discrepancy between dissimilarities derived from rating data and corresponding interstimulus distances in MDS spatial configurations of various dimensionalities: Stress (Kruskal & Wish, 1978), S-Stress (Takane, Young, & de Leeuw, 1977), and 1-RSQ. Stress is based upon MDS distances, S-Stress is based upon squared MDS distances, and 1-RSQ is the proportion of variance in dissimilarities not accounted for by a regression of

dissimilarities onto MDS distances. Smaller values indicate better fit for all three measures. Figure 2 shows 1-RSQ, S-Stress, and Stress as a function of dimensionality. ALSCAL does not compute a one-dimensional solution with the individual differences approach. Values for all three measures are larger in magnitude than corresponding values reported by Kleiss (in press, Exp. 1) for data collected with the full three-window display configuration. However, present values are roughly comparable to those reported by Kleiss (in press, Exp. 2) with a single forward-oriented display window. Therefore, the fit of the data is consistently poorer with the single-window displays regardless of their orientation. A common criterion for identifying correct dimensionality is the occurrence of an "elbow" in the plot of values indicating the point at which increasing dimensionality provides diminishing improvement in fit. There is no evidence of an elbow in the plots for S-Stress or Stress. There is, however, an indication of an elbow at dimensionality equal to 4 for 1-RSQ.
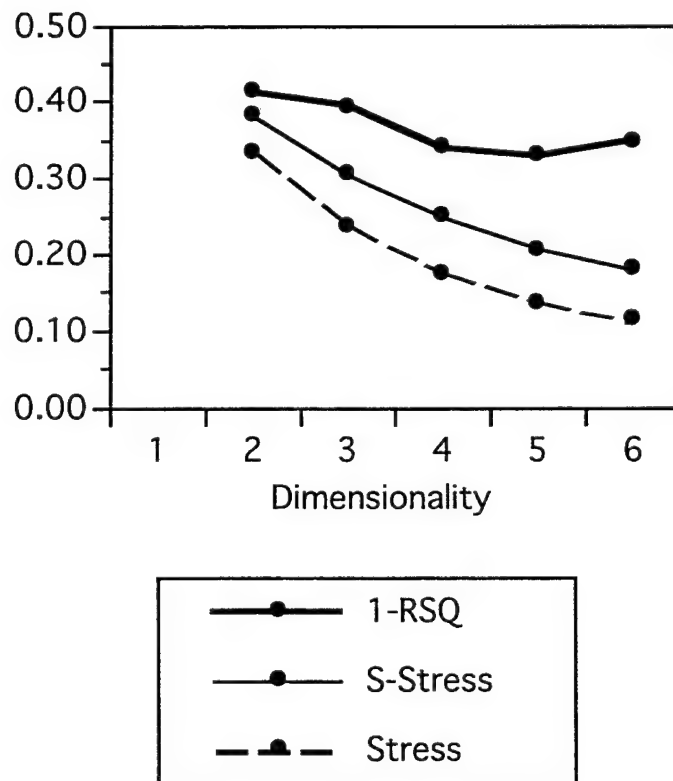
Figure 2
1-RSQ, S-Stress, and Stress as a Function of Dimensionality

As a further step in assessing the structure in the present data, intercorrelations were calculated between dimensional coordinates for the two-, three-, and four-dimensional solutions in the present experiment and the three- and two-dimensional solutions of Kleiss (in press, Exps. 1 & 2, respectively). These are shown in Table 1 below. If any of the present solutions contain structure similar to that in the experiments of Kleiss (in press), one would expect each dimension in Experiment 1 or 2 of Kleiss (in press) to be uniquely related to at least one dimension in one of the present solutions. One can see in Table 1 that Dimension 1 of the present two-dimensional solution is related to both Dimensions 1 and 3 in the three-dimensional solution of Kleiss (in press, Exp. 1) and does not, therefore, reflect information unique to either of those two dimensions. Dimension 1 in the present two-dimensional solution is also related to Dimension 1 in the two-dimensional solution of Kleiss (in press, Exp. 2), but Dimension 2 is not highly related to Dimension 2 of Kleiss (in press, Exp. 2). Hence, the present two-dimensional solution does not appear to contain structure similar to that in either experiment of Kleiss (in press)..A somewhat similar pattern is evident with the present three-dimensional solution. Dimension 1 is related to both Dimensions 1 and 3 of Kleiss (in press, Exp. 1) whereas none of the dimensions is related to Dimension 2 of Kleiss (in press, Exp. 2). Turning to the present four-dimensional solution, Dimensions 1 and 2 are related to Dimension 1 of the three-dimensional solution of Kleiss (in press, Exp. 1) whereas Dimension 3 is uniquely related to Dimension 3 of Kleiss (in press, Exp. 1) and Dimension 4 is uniquely related to Dimension 2 of Kleiss (in press, Exp. 1). Hence, the present four-dimensional solution contains the three-dimensional structure of Kleiss (in press, Exp. 1) plus some additional structure related to Dimension 1 of Kleiss (in press, Exp. 1) which is unique to this experiment. The four-dimensional solution will, therefore, be considered.

Table 1. Intercorrelations Among Coordinates from the Two-, Three-, and Four-Dimensional Solutions in the Present Experiment, and the Three- and Two-Dimensional Solutions from Kleiss (in press, Exps. 1 & 2, respectively)

| | Kleiss (in press) | | | | |
| | Experiment 1 | | | Experiment 2 | |
	1	2	3	1	2
Present Experiment					
2-Dimensional Solution					
1	.79	-.18	-.71	.78	.37
2	.66	-.31	.03	.57	.38
3-Dimensional Solution					
1	.78	-.13	-.71	.74	.35
2	-.52	.78	.26	-.72	-.27
3	-.43	-.44	-.32	-.07	-.37
4-Dimensional Solution					
1	-.66	.32	-.03	-.58	-.40
2	.73	-.11	-.28	.50	.58
3	-.52	.09	.75	-.65	-.05
4	.09	-.89	-.44	.48	-.04

A feature of ALSCAL output provided with the individual differences option is subject weights which reflect the relative importance of each dimension for individual subjects. The extent to which a given subject's weights are proportional to the group average is indexed by "weirdness." A weirdness value near 1.00 indicates that a subject has one comparatively large weight and the others small. A weirdness value near zero indicates that weights are exactly proportional to the group average. Squared subject weights averaged across subjects provide estimates of variance explained by each dimension for the group. These must be taken as estimates because the data are assumed to be ordinal and do not satisfy the metric assumptions underlying usual interpretations of variance. Table 2 shows weirdness values and subject weights for individual subjects plus squared subject weights averaged across subjects for each dimension. Note that Dimension 2 explains the largest proportion of variance in similarity ratings and is the most important dimension. Next in order of importance are Dimensions 1, 3, and 4, respectively. None of the weirdness values are particularly large indicating a fairly high degree of correspondence among subjects with regard to the relative weighting of dimensions.

Figure 3 shows the four-dimensional ALSCAL solution depicted in two three-dimensional scatter plots. The horizontal plane in each plot defines Dimensions 1 and 2. The vertical axis in the upper plot defines Dimension 3 whereas the vertical axis in the lower plot defines Dimension 4. Codes for various scene conditions are as follows: F = flat terrain, R = rolling terrain, S = sparse hills, D = dense hills, T = texture, E = texture plus evenly spaced trees, and G = texture plus grouped trees.

Table 2. Subject Weights and Weirdness Values for Individual Subjects Plus Average Squared Subject Weights for Each Dimension.

| Subject | Weirdness | Subject Weights | | | |
		Dim. 1	Dim. 2	Dim. 3	Dim. 4
1	0.4072	0.5017	0.2742	0.2439	0.6169
2	0.1959	0.4199	0.2440	0.3742	0.3565
3	0.3932	0.2354	0.3045	0.6588	0.3483
4	0.1796	0.4262	0.2609	0.3063	0.3410
5	0.3082	0.6670	0.5363	0.2733	0.2593
6	0.1955	0.3413	0.5912	0.4023	0.3262
7	0.5135	0.5791	0.7034	0.1731	0.1181
8	0.3105	0.2677	0.1644	0.3818	0.3340
9	0.4946	0.1704	0.7683	0.4327	0.1901
10	0.3074	0.4109	0.1573	0.4327	0.3263
Average Squared Subject Weights		0.1831	0.2069	0.1514	0.1187
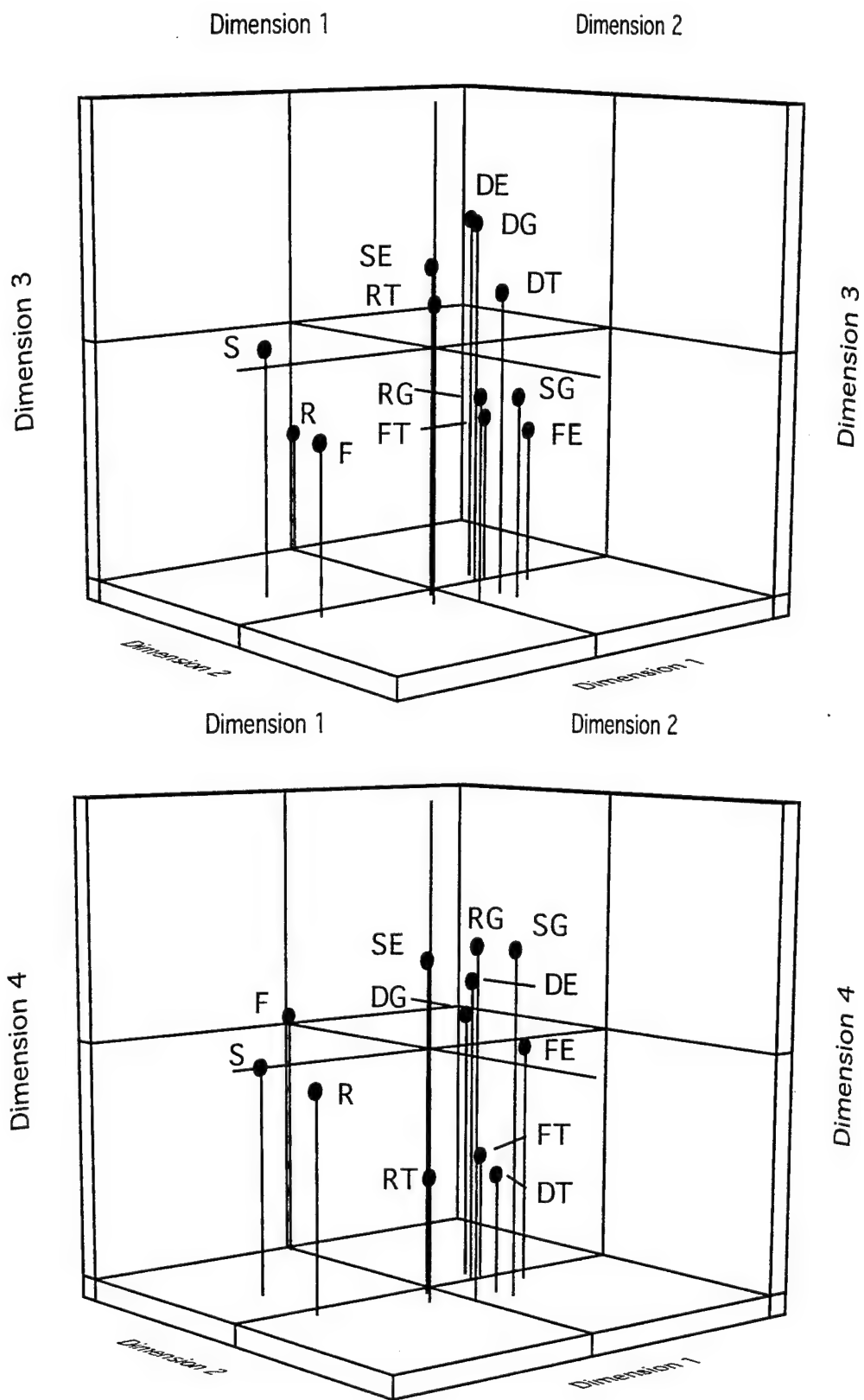
Figure 3.
Spatial Configurations Depicting 4-Dimensional Solution.

Inspection of the upper plot in Figure 3 reveals that all scenes containing texture on the terrain are clustered near the middle of Dimensions 1 and 2. At the left end of the spatial configuration near the end of Dimension 1 are the two scenes with untextured hills. At the back of the spatial configuration near the end of Dimension 2 is the scene with completely flat and featureless terrain. The positioning of scenes along the Dimension 1 axis reveals a difference between scenes with untextured hills versus all other scenes. The two scenes with untextured hills exhibit a mosaic of triangular terrain polygons defined by contrast differences between adjacent polygons. The scene with completely flat and featureless terrain is positioned among remaining scenes near the middle of the Dimension 1 axis, indicating that these scenes are not defined by the presence of any particular feature but by the absence of triangular polygons. Hence, Dimension 1 would appear to reflect the presence or absence of large polygonal surfaces defined by luminance differences.

The positioning of scenes along the Dimension 2 axis reveals a distinction between scenes with optical discontinuities versus the scene with completely flat and featureless terrain. Optical discontinuities are provided by both texture on the terrain as well as polygons defining untextured hills. Hills, therefore, exhibit two distinctly different properties, one which differs from texture (Dimension 1) and one which is more similar to texture (Dimension 2). The important property related to Dimension 1 is linear boundaries defining untextured terrain polygons. The shape of boundaries is unimportant in Dimension 2. Note that scenes with trees are positioned about equally in relation to the Dimension 2 axis as scenes with texture alone, arguing that trees do not add to the optical discontinuities already provided by texture. The critical property related to Dimension 2, therefore, appears to be the global distribution of texture on the terrain rather than discrete objects. Dimension 2 in the present experiment is related to Dimension 1 in Kleiss (in press, Exp. 1) which also revealed a distinction between textured and untextured terrain. Dimension 2 differs in that untextured hills are also perceived to have a texture-like quality whereas they were not in the previous experiment. Hence, the distribution of boundaries defining untextured terrain polygons is a more salient property of scenes in this experiment. Taken together, Dimensions 1 and 2 in the present experiment reveal a distinction between textured and untextured terrain similar to that in Dimension 1 of Kleiss (in press, Exp. 1). In addition, present results reveal increased sensitivity to two properties of untextured hills.

Scenes nearest the upper end of Dimension 3 contain steeply sloped hills whereas scenes nearest the lower end of Dimension 3 generally contain flat or rolling terrain. This ordering of scenes supports an interpretation of Dimension 3 consistent with variation in terrain shape. Dimension 3 is related to Dimension 3 of Kleiss (in press, Exp. 1) (see Table 3) which also related to terrain shape. Unlike Kleiss' (in press, Exp. 1, Dimension 3) results, there is much less evidence of discrimination among scenes with respect to the slope and spacing of hills. However,

as was the case in Kleiss' previous experiment, there is evidence that trees on the terrain facilitate perception of steeply sloped hills.

Scenes near the upper end of Dimension 4 (lower plot in Figure 3) contain trees whereas scenes near the lower end of Dimension 4 contain texture alone. Scenes lacking texture or trees are positioned near the middle of the dimension, suggesting a qualitative distinction between texture and trees. This dimension is related to Dimension 2 of Kleiss (in press, Exp. 1) (see Table 3) which revealed a similar distinction between texture and trees. Because texture is related to both Dimension 2 and 4, it plays a dual role in scenes. Trees stand out as discrete elements in scenes, suggesting that the importance of texture dimension relates to localized properties of individual scene elements. Texture blotches, therefore, would appear to be important both as discrete scene elements in this dimension as well as defining a global distribution of elements in Dimension 2. The qualitative difference between texture blotches and trees may relate to a difference between flat and vertical objects. The validity of this distinction is supported by evidence that verticality is a factor affecting performance of other simulated low-altitude flight tasks (e.g. Martin & Rinalducci, 1983). In addition, Harker and Jones (1980) discuss a difference between flat and vertical objects based on geometric transformations.

DISCUSSION AND CONCLUSIONS

Present evidence that texture (Dimensions 1 and 2), objects (Dimension 3) and terrain shape (Dimension 4) are perceived as unique scene properties is consistent with results obtained by Kleiss (in press, Exp. 1) using the full three-window display configuration. Hence, the lack of evidence for interpretable multidimensional scene structure with scenes displayed on the single forward-oriented window (Kleiss, in press, Exp. 2) can be attributed to absence of information obtained exclusively off-axis from the heading direction. Because exactly the same scenes were used in this experiment as in the experiment of Kleiss (in press, Exp. 2) the difference cannot be attributed to factors such as the type or quantity of scene features. Also, because subjects in the present experiment oriented their gaze toward the side window, the relevant information does not appear to be based upon peripheral stimulation of the retina. The present advantage for scenes viewed on the side-oriented display window is similar to results reported by Wolpert (1990) that perception of self-motion events (e.g., changes in speed and altitude) was better when the stimulus was a view perpendicular to the heading direction than a view in the direction of heading. Wolpert attributed this advantage to superior information provided by parallel optic flow off-axis from the heading direction compared to expanding optic flow in the direction of heading. The crucial point is that what is relevant in flight simulator visual scenes is not defined simply by the type or quantity of features in scenes. Rather, one must also take into account relationships among scene features produced by one's motion within the environment. These relationships are specific to the region of the environment sampled as one moves.

Wolpert (1990) identified one type of information available off-axis from the heading direction, parallel optic flow. Present evidence for multidimensional scene structure implies multiple sources of information. Investigations of self-motion perception have typically focused on texture variables (e.g., Flach, Hagen, & Larish, 1992; Wolpert, 1988). In the present experiment, texture is most clearly reflected in Dimensions 1 and 2. Present results, therefore, point to two additional sources of information, objects and terrain shape (Dimension 3 & 4), which have not received a great deal of attention in the self-motion perception literature. Present results, therefore, suggest extending analyses to include information provided by these scene properties.

It is important to note that despite the evidence for interpretable multidimensional scene structure, the fit of the data in the present experiment remained considerably poorer than that obtained with the full three-window display configuration (Kleiss, in press, Exp. 1). Hence, the side-oriented display window would appear to remain deficient in at least some type of information compared to the three-window display configuration. The three-window display offers at least two potentially important advantages over the single side-oriented display window. First, the larger display area provides greater peripheral stimulation of the retina regardless of the orientation of one's eyes within the environment and this could be a secondary factor affecting scene perception with the MDS task. Second, the larger display area also affords the opportunity to direct one's gaze to regions of the simulated environment larger than a single display window.

These two possibilities have implications for display design and training in that if stimulation of the far periphery is important then displays should optimally be larger in size than a single window in the present display (approximately 80 deg by 70 deg). A larger display would entail an additional investment in image channels or a corresponding reduction in resolution that would accompany projecting available imagery over a larger display area. Large displays are sometimes precluded by technological considerations, for example, helmet-mounted displays or sensor-aided vision (e.g., night vision goggles) with limited field of view. A requirement for a large display area would render such systems fundamentally limited and would require consideration of strategies for overcoming limitations.

If the poor fit of the data in the present experiment results from lack of integration of information across regions of the environment larger than a single display window, this limitation could possibly be overcome with a small display that was tracked to the subject's head or eye movements. The role of scanning or tracking could be investigated with the three-window display configuration by constraining subjects' vision with a device that limited viewing area, but allowed vision to be directed to different areas of the display. Results similar to those obtained with the full three-window display configuration (Kleiss, in press, Exp. 1) would provide evidence that instantaneous viewing area was not the critical factor mediating those results. If scanning or tracking should prove to be important for perceiving relevant information in scenes, a fruitful area

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for future investigation would be strategies for improving the efficiency of eye behavior during low-altitude flight.

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